Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Robust Motion Planning for Marine Vehicle Navigation

Matthew B. Greytak and Franz S. Hover
Department of Mechanical Engineering, Massachusetts Institute of Technology.
Cambridge, MA, USA

ABSTRACT

In this paper we consider the control of a small autonomous underactuated surface vessel such as a harbor patrol craft. The maneuvering problem can be solved using the Maneuver Automaton motion planning framework to navigate around obstacles to a destination. This technique is useful for docking maneuvers and other complex tasks. We demonstrate how the inclusion of waypoints adds global position feedback to the motion plans, making them more robust to disturbances. An analysis of the position variance evolution throughout the plan shows that using waypoints limits the position uncertainty and consequently the risk of collision with obstacles. We present simulations and experimental results for a surface vessel. The plans are optimal with respect to a metric that includes both plan duration and collision probability.

KEY WORDS: motion planning; maneuvering; navigation; waypoint tracking; collision avoidance; autonomous vehicles.

INTRODUCTION

Autonomous marine vehicle control is a multi-scale problem. At one extreme, the vehicle must traverse large open regions of the sea. The standard open-ocean navigation technique is to drive between waypoints whose locations are chosen so that passage between them is safe and efficient. The line-of-sight waypoint path-following algorithm is easily implemented with provable stability (Pettersen and Lefeber, 2001). At the other extreme, marine vehicles must perform docking maneuvers and safely navigate through harbors and other cluttered environments. Motion planning techniques can generate open-loop maneuver sequences to achieve these tasks, but the plans are sensitive to modeling errors and disturbances. In this paper we unify waypoint path following and motion planning into a single framework. The waypoints add robustness to the plans by introducing a mechanism for global position feedback, as shown by an analysis of the position variance evolution throughout the plan.

While the techniques used in this paper can be applied to any autonomous vehicle including those operating in 6 degrees of freedom, we focus our simulations and experiments on a small surface vessel appropriate for autonomous harbor patrols. Such a vehicle must plan trajectories through both large open spaces and confined environments. Using autonomous patrol vessels would reduce the manpower required to enforce safety and security in the harbor. The navigation task is to find a safe and efficient route through the known obstacles to a goal position defined by an external source such as a human coordinator.

Arbitrary paths may not be realizable by the vehicle due to dynamic constraints, such as acceleration bounds, and kinematic constraints, such as nonholonomic systems. These issues are compounded if the vehicle is underactuated. Therefore for autonomous vehicle motion planning we focus on kinodynamic motion planning rather than path planning.

An effective kinodynamic motion planning framework is Frazzoli's Maneuver Automaton (MA) (Frazzoli, Dahleh, and Feron, 2005). The framework combines motion primitives (discrete maneuvers) and trim trajectories (constant-speed conditions) into motion plans that, due to their construction, are guaranteed to be realizable by the vehicle. Furthermore, the plans can incorporate the fully nonlinear dynamics and kinematics of the vehicle.

While the maneuver automaton is a framework for representing motion plans, it alone does not identify admissible maneuver sequences. To find admissible plans, one can use dynamic programming (Schouwenaars, Mettler, and Feron, 2003) or Rapidly-Exploring Random Trees (RRTs) (Hsu, Kindel, Latombe, and Rock, 2002). An improvement to the RRT algorithm incorporates an optimal obstacle-free planner as a sub-loop of the randomized algorithm (Frazzoli, Dahleh, and Feron, 2002). Tan, Sutton, and Chudley (2005) applied this algorithm to a planar autonomous underwater vehicle (AUV) simulation. In this paper we use A* (Hart, Nilsson, and Raphael, 1968), an optimal graph search algorithm, to build plans that are optimal in the maneuver automaton domain.

Feedback for motion plans has been largely ignored in the literature. The output of kinodynamic planners is an open-loop plan of either control inputs or maneuvers; even if the maneuvers themselves have low-level feedback, the plan as a whole is still open-loop. As a result, modeling errors or external disturbances can disrupt the motion plan